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Phonetic Typology and Positional Allophones for Alveolar Rhotics in Catalan

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Abstract

The present study reports electropalatographic and acoustic data on the positional and contextual characteristics of alveolar taps and trills in Majorcan, Valencian and Eastern Catalan. The two consonant classes are invariably opposed by degree of tongue dorsum contact and F2, but only differentiated by place of articulation when constriction location for the trill is sufficiently retracted. Trills are produced with less than three contacts and may exhibit a single contact in utterance-initial position and, less often, in /Cr, VrV/ sequences. Word-final and, to a lesser extent, preconsonantal rhotics are implemented as taps in Majorcan and Valencian, and strengthened into trills in Eastern Catalan. Moreover, there appears to be an inverse relationship between initial strengthening, and intervocalic weakening and the absence of syllable-final strengthening, for Valencian rhotics, which could be indicative of a pattern of intersegmental organization. Shortening and articulatory reduction turned out not to be necessarily related for extremely short Valencian taps, which undergo much undershoot intervocalically but are highly constricted in /Cɾ, rC/ sequences. Other research aspects such as devoicing and intergestural timing for Catalan alveolar rhotics are also investigated.

1 Introduction

Alveolar taps ([ɾ]) and trills ([r]) exhibit different articulatory and timing characteristics in line with the aerodynamic constraints involved in their production. Alveolar taps are produced with a fast, ballistic tongue tip raising movement and a single short apicoalveolar contact. Tap duration ranges between 15 and 30 ms when languages as diverse as Tamil, Spanish, Greek and Catalan are taken into consideration [McDonough and Johnson, 1997, p. 8; Navarro Tomás, 1918, p. 385; Nicolaidis, 2001, p. 75; Recasens, 1986, p. 80]. Alveolar trills usually have two or three such short apical contacts separated by short oral openings [Lavoie, 2001, p. 143; Lindau, 1985, p. 160]. Trilling is initiated when there is enough pressure difference across the apicoalveolar constriction to set the tongue tip into vibration. As the air exits through an open channel,

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a pressure reduction and the Bernoulli effect associated with it causes the tongue tip to reach the appropriate contact position and the oral pressure level to increase for the next vibration cycle [McGowan, 1992; Solé, 2002].

While specific articulatory characteristics render these different mechanisms possible in intervocalic position, the fact is that rhotics are highly variable regarding manner and place of articulation depending on position, context, dialect and speech rate [Lindau, 1985; Nieto-Castanon et al., 2005]. The main purpose of our study is to uncover articulatory and acoustic changes for /ɾ/ and /r/ mostly as a function of word and utterance position. Data will be reported for three Catalan dialects, i.e. Majorcan, Valencian and Eastern Catalan, where relevant phonetic differences in rhotic implementation are known to occur.

The distribution of Catalan taps and trills is basically the same to that found in Spanish. Both consonants are set in contrast in intervocalic word-medial position, e.g. [ˈpaɾə] *pare* ‘father’ vs. [ˈparə] *parra* ‘grapevine’. In other syllable-initial conditions, they are in complementary distribution: trills occur exclusively stem-initially ([ram] *ram* ‘branch’, [pɾɛruˈma] *pre-romà* ‘pre-Roman’) and word-medially after a heterosyllabic consonant ([ˈonrə] *honra* ‘honor’), and taps appear after a tautoyllabic oral stop or /f/ ([pɾat] *prat* ‘meadow’, [bɾaw] *brau* ‘brave’). The two rhotics are noncontrastive syllable-finally whether before a heterosyllabic consonant or in word-final position before a pause. In this case, the final phonetic outcome appears to be a tap in Valencian and presumably Majorcan ([ˈkaɾtə] *carta* ‘letter’, [maɾ] *mar* ‘sea’) and a trill in Eastern Catalan ([ˈkartə], [mar]). A comparative analysis of syllable-final rhotics may be carried out among all three Catalan dialects in preconsonantal position but only between Valencian and Eastern Catalan word-finally. This is so since /r#/ (the symbol /r/ is used both for trills and for non-contrastive syllable-final rhotics in this paper) is kept almost systematically in Valencian, is practically absent in Majorcan, and occurs only in a group of lexical items including monosyllables, neologisms and learned words in Eastern Catalan.

1.1 Articulatory and Spectral Properties

A first research topic is whether Catalan dialects differ regarding the articulatory and acoustic properties of taps and trills. Some support for dialect-dependent place differences may be found in the literature. Trills appear to be front alveolar or postdental in Degema and South American Spanish dialects and postalveolar in Russian and Eastern Catalan, and alveolar taps are front or centroalveolar in Spanish and Eastern Catalan and perhaps more retracted in Greek [Fernández, 2000, p. 178; Gili Gaya, 1921, pp. 272–273; Lindau, 1985, p. 161; Nicolaidis, 2001, p. 74; Recasens and Pallarès, 1999]. Phonetic differences may also apply to the overall articulatory configuration and the spectral characteristics. Thus, the dental, alveolar and retroflex trills in Toda show an F1 increase (409, 617 and 565 Hz) and an F2 decrease (1,573, 1,390 and 1,350 Hz) with tongue body backing and lowering, and an F3 decrease as place of articulation becomes more posterior (2,577, 2,535 and 2,310 Hz) [Spajić et al., 1996]. F3 is also higher for prealveolar taps than for postalvelar taps in Tamil [Narayanan et al., 1999]. According to some of the studies mentioned above, formant frequency values for other languages reveal that more anterior trills also have a higher F2 and F3 than more posterior ones (1,600–1,800 vs. 1,200–1,450 Hz; 2,300–2,500 vs. 2,300 Hz or lower).

Another open issue is whether taps and trills are set invariably in contrast. This appears to be the case in Eastern Catalan where, in comparison with /ɾ/, /r/ is more posterior, and exhibits a higher F1 (370–606 vs. 340–516 Hz) and a lower F2 (1,286–1,440 vs. 1,527–2,024 Hz) since it involves a lower predorsum and jaw and some dorsopharyngeal approximation, and a lower F3 (2,383–2,437 vs. 2,410–2,679 Hz) since it is articulated with a more retracted constriction [Recasens and Pallarès, 1999]. Moreover, trills are produced with a longer first contact than taps, exhibit more gestural anticipation during a preceding antagonistic front vowel, and are more resistant to coarticulatory vowel effects in constriction location and tongue body configuration.

1.2 Position-Dependent Strengthening and Weakening Mechanisms

A second research goal is how rhotic realization varies with position and context. This study will also investigate if, analogously to consonants of other manners of articulation, rhotics undergo strengthening utterance-initially and syllable-initially after a heterosyllabic consonant, and whether they undergo articulatory weakening intervocalically. These position-dependent effects could parallel, for example, the behavior of /ʃ/ in Catalan dialects where intervocalic [(j)ʃ] ([ˈkajʃa] ‘box’) alternates with word-initial and postconsonantal [tʃ] ([tʃaˈra] ‘to speak’, [ˈpuntʃa] ‘sting’). A related research topic is the realization of syllable-final rhotics and the extent to which the observed dialectal variability may be accounted for through strengthening or weakening depending on the case.

1.2.1 Syllable-Initial Rhotics

Trills placed at the edges of the utterance should participate in a general trend for phonetic segments to reinforce postpausally [Fougeron and Keating, 1997]. A potential strengthening correlate could be an increase in duration and number of contacts, as in Arop-Lokep where trills exhibit usually three contacts utterance-initially and two contacts intervocalically and preconsonantally [Raymond and Parker, 2005]. Phonetic studies on Spanish and Catalan trills reveal, however, that the number of contacts is the same or less, not more, word-initially than intervocalically, and that postconsonantal trills do not exhibit more than two or three contacts either [Lavoie, 2001, p. 143; Malmberg, 1950, p. 139; Navarro Tomás, 1916; Recasens, 1986, p. 77].

Strengthening is expected to be cued by other phonetic properties, namely, the absence of central contact loss and a high degree of resistance to contextual variations. The strengthening correlates of place of articulation and tongue dorsum configuration remain unclear, however. It could be that, analogously to utterance-initial consonants in other languages [Fougeron and Keating, 1997], reinforced realizations of alveolar rhotics show an increase in overall tongue contact and in F2. The opposite outcome is also possible, if the characteristic phonetic properties of trills are enhanced under strengthening conditions and in accordance with data for other consonant realizations involving similar articulatory characteristics [e.g. strongly dark /ɫ/ in Majorcan Catalan; Recasens and Espinosa, 2005].

Weakening may account for trill simplification if the degree of aperture at constriction location is too large, there is not enough apical tension and/or the airflow volume is too small. Intervocalic trills may be realized as taps more or less often in Standard Swedish and Spanish, and have tap or approximant allophones in Persian and Hausa [Blecua, 2001; Lindau, 1985, pp. 158, 161]. In addition to a decrease in constriction degree, these weakened realizations are expected to exhibit a decrease in overall tongue contact and some F2 lowering.

Strengthening and weakening could also affect taps. Syllable-initial taps after a tautosyllabic consonant are expected to strengthen. Intervocalic taps, on the other hand, could weaken through extreme gestural undershoot, mostly so next to vowels involving a large distance between the tongue and the palate. Linguopalatal contact data for Catalan, Greek, Japanese and Ibibio reveal indeed that taps are often realized as approximants through failure to achieve a complete closure [Baltazani, unpublished; Barnils, 1933, p. 22; Connell, 1992, p. 14; Nicolaidis, 2001, p. 74; Sawashima and Kiritani, 1987]. Regarding the Catalan dialects under analysis, the fact that taps and approximants may undergo elision in intervocalic position in Valencian (e.g. [en'ka] for *encara* 'still', [a'oɾ] for the suffix *-ador* with approximant [ð] in other Catalan dialects) suggests that intervocalic /ɾ/ ought to be specially reduced in this dialect.

1.2.2 Syllable-Final Rhotics

The statement that the contrast between taps and trills is neutralized before a heterosyllabic consonant and before a pause is not explicit about the phonetic implementation of syllable-final rhotics. It is commonly believed that taps and trills occur in free variation in those two positions [Quilis and Fernández, 1972, p. 131]. However, while the use of one rhotic or the other may pass unnoticed among speakers of a given community, descriptive data summarized above suggest that dialects such as Valencian and presumably Majorcan favor weaker tap realizations while others such as Eastern Catalan favor stronger trill productions. Similar differences apply to Spanish dialects: final rhotics are realized as taps in Peninsular Spanish and as trills in Mexican Spanish [Harris, 1969, p. 49; Navarro Tomás, 1972, p. 115].

It also needs to be seen whether the alternation between taps and trills applies to the same extent in dialects favoring taps and in those favoring trills, or whether variability is more frequent in the former group of dialects or in the latter. Data from the literature reveal that preconsonantal rhotics in languages not exhibiting reinforcement such as Spanish usually involve one contact or approximation though multiple-contact realizations may also be allowed in favorable contextual conditions and in emphatic speech [Gili Gaya, 1921, p. 275; Malmberg, 1950, p. 131]. On the other hand, languages or dialects where rhotics are supposed to undergo strengthening syllable-finally may also show one-contact productions in preconsonantal position [Eastern Catalan; Recasens and Pallarès, 2001, p. 52], while systematic trilling is more prone to occur utterance-finally [Eastern Catalan and Mexican Spanish; Recasens, 1986, p. 77; Malmberg, 1965]. A related research topic is whether the articulatory implementation of syllable-final taps and trills coincides with that of syllable-initial taps and trills, or whether syllable-final realizations are more reduced than syllable-initial ones (e.g. in terms of the number of contacts).

Analogously to initial strengthening, syllable-final strengthening could also be correlated with constriction degree and location and tongue dorsum configuration. Speakers could implement strengthening through an increase in constriction degree and in dorsopalatal contact size as for initial consonants in general, or else through little dorsopalatal contact in line with specific production requirements for trills and with the trend for syllable-final consonants to undergo some articulatory reduction. Moreover, weaker rhotics could sound like clear /l/ as in Southern Spanish and Argentinian Spanish if the two sound classes share an F2 frequency about 1,500–2,000 Hz [Malmberg, 1950, p. 145;

Navarro Tomás, 1975, pp. 184–187], and be elided or replaced by approximant or vocalized realizations.

1.3 Other Aspects

The present paper will also deal with the insertion of a short vocalic element resulting from the temporal adjustments between the gestures for the rhotic and for the adjacent consonant in /Cɾ/ and /rC/ sequences. Data from the literature reveal that this vowel segment is somewhat centralized, and that its duration and formant frequencies depend on the transconsonantal vowel and on place, manner and voicing in the contextual consonant. Moreover, the short vowel in question is somewhat shorter in /Cɾ/ than /rC/ clusters, i.e. between 30 and 40 ms for /Cɾ/ and up to 50–55 ms for /rC/ in Catalan and Spanish [Malmberg, 1950, p. 132; Quilis, 1981, pp. 298–299; Recasens, 1986, pp. 81–84]. A relevant issue is whether there is an inverse relationship between the duration of this oral opening period and the duration of the rhotic, i.e. if the vocalic element occurs more frequently and is longer in dialects with shorter rhotics in clusters. The presence of a vocalic release of a relatively fixed quality after a single-contact rhotic utterance-finally will also be investigated [see, for Spanish dialects, Navarro Tomás, 1975, p. 181].

Attention will also be paid to devoicing and the presence of friction in rhotics. Devoicing may occur when the supraglottal pressure level is too high (utterance-initially and in clusters) or too low (utterance-finally) to allow continuous vocal fold vibration; prominent gestural anticipation for the trill may also account for the devoicing of post-pausal /#r/. Turbulent airflow is found when respiratory pressure becomes too high or if resistance to airflow causes the airflow volume to decrease below the critical value needed to instantiate apical vibration [Laver, 1993, p. 264; Solé, 2002; Widdison, 1998].

1.4 Summary

Two major research topics on Catalan rhotic consonants will be explored in the present study:

(1) Articulatory and acoustic differences between taps and trills in general and between different consonant classes within each rhotic category. Rhotics are expected to differ in number of contacts, duration, place of articulation, tongue dorsum configuration and formant frequency as a function of dialect and position.

(2) The phonetic properties cueing rhotic weakening intervocalically, and rhotic strengthening utterance-initially, postconsonantally and syllable-finally in specific dialects. Possible strengthening cues are an increase in the number of contacts, the lengthening of the first contact and the absence of articulatory reduction at constriction location. Rhotic weakening should account for segmental shortening and constriction widening, and for trill simplification.

Other research issues are the frequency of occurrence and duration of a vocalic element often showing up in /Cɾ/ and /rC/ clusters, and the contextual and positional factors inducing devoicing and assibiliation in rhotics.

2 Methodology

2.1 Recordings

Linguopalatal contact (EPG) and acoustic data were obtained from a list of sentences including rhotics in all positions and long stretches of spontaneous speech for Majorcan and Valencian, and from a list of two-word sequences with a syllable-final rhotic for Eastern Catalan.

Five male speakers of Majorcan Catalan and 5 male speakers of Valencian Catalan between 30 and 50 years of age were asked to read the short sentences of table 1 five times each at a comfortable rate. All subjects use Majorcan or Valencian on a regular basis in their everyday life. The Majorcan speakers came from different areas in the island of Majorca, i.e. A.R. (from Manacor), B.M. (Algaida), M.J. (Valldemossa), N.D. (Palma), C.A. (Santanyí). The Valencian speakers were born and live in the Valencian country and use different regional subdialects, i.e. Northern Valencian (speakers A.V. and M.S. from Vinaròs and Castelló, respectively), Central Valencian (speaker J.M. from Picassent), and Southern Valencian (speakers V.B. and V.G. from Marina Baixa and Costera).

In the sentence list, the trill is found utterance-initially before /e/, postconsonantally after /n, l/, and intervocalically next to vowels differing in height and fronting in the sequences /ari, are, ara/. On the other hand, the tap occurs between vocalic segments differing in height and fronting in the strings /eɾi, aɾa, wɾe/ (a position which will be referred to as intervocalic in the paper), and after tautosyllabic labial and velar consonants not interfering with the tongue tip in the clusters /pɾ, bɾ, gɾ/. Utterance-finally /r/ is found after /i, e, a, ɔ/ in Valencian. Small dialectal differences were only available for preconsonantal /r/ that preceded /m, t, d, n, l, ʃ, g/ in Majorcan and /p, b, m, d, s, k, g/ in Valencian. Dialects also differed regarding unstressed /a, e/, which reduce to [ə] in Majorcan but not in Valencian.

After recording the sentences of table 1, all Majorcans and 3 Valencians (J.M., V.G., A.V.) were asked to record a story. Data were processed for all occurrences of intervocalic taps (183 words where /ɾ/ shows up in different vowel contexts), postconsonantal taps (91 words with the clusters /pɾ, bɾ, fɾ, tɾ, dɾ, kɾ, gɾ/), a few intervocalic and postconsonantal trills (40 words), a few prepausal rhotics (22 words), and a larger number of preconsonantal rhotics (123 words with the clusters /rf, rm, rt, rd, rn, rl, rs, rk/).

Sentences in table 2 were recorded five times each by the 3 Eastern Catalan male speakers D.R., J.P. and J.S. at the University of Reading, England, back in 1992. In the table, the rhotic appears at the end of the first word before /t, n, l, s, ʎ, ʒ, k/ and utterance-finally after the vowel /a/.

EPG data were gathered with the Reading EPG-3 system every 10 ms using artificial palates equipped with 62 electrodes [Hardcastle et al., 1989]. Acoustic data were digitized at 10 kHz and processed with a Kay CSL analysis system synchronously with the EPG data. Laryngographic data were also recorded by the 3 Eastern Catalan speakers and analyzed simultaneously with the linguopalatal contact and acoustic signals for the sentences of table 2. Data for /#r, Cr/ for speaker C.A. were excluded from analysis since he performs the trill as uvular, and those for /rn, rl/ were not processed in words where the two clusters were judged to undergo regressive assimilation, i.e. *intern* for speakers B.M. and C.A., *forn* for A.R., M.J., N.D. and C.A., and *parla* for B.M. and M.J.

2.2 Analysis

Electrodes in the EPG contact configurations are arranged in eight rows and in four columns at each half of the artificial palate (fig. 1). The frontmost row 1 (just behind the upper teeth) appears at the top of the graphs and the backmost row 8 (just in front of the soft palate) at the bottom; column 1 is the outermost column and colum 4 the innermost one. The surface of the palate was subdivided into two articulatory zones for segmentation and data analysis, i.e. an alveolar zone including the four frontmost rows and a palatal zone including the four backmost rows.

Contact identification and duration for rhotics were measured for the only contact period for taps, and for all contact and opening phases for trills, on the EPG tracings with the help of waveform and spectrographic displays. Simultaneous representations of these three signals such as those in figure 2 were used for that purpose. Overall trill durations were taken to be the sum of the durations of the corresponding contact and opening periods. Contact onset and offset were identified at the first frame showing activation or deactivation, respectively, of at least one electrode located at the four central alveolar columns [Recasens and Pallarès, 1999]. If the rhotic exhibited no electrode activation in this area, consonant onset was taken to occur at the first frame showing some constriction narrowing towards the center of the alveolar zone and/or a significant decrease in formant amplitude or an F1 inflection on the spectrographic representations. An analogous criterion was used to determine the offset of specially open rhotics. The acoustic criterion proved useful for rhotic segmentation in the case of the clusters /nr, lr/ where C1 and C2 could share the same or a close place of articulation.

Duration was also analyzed for the vocalic portion occurring between the rhotic and the adjacent consonant in /Cɾ, rC/ sequences and after word-final rhotics before a pause. Its boundaries were determined

Table 1. List of sequences read by the Majorcan and Valencian speakers in phonetic transcription and in Catalan orthography

Utterance-initial trill			
/#re/	Maj. [rennəl rej ˈsɔl]	*regna el rei Sol*	‘the Sun King reigns’
	Val. [reŋnal rej ˈsɔl]		
Postconsonantal trill			
/nr/	Maj. [ən rəmon ˈʎuʎ]	*en Ramon Llull*	‘Ramon Llull’[1]
	Val. [en ramon ˈʎuʎ]		
/lr/	Maj. [əz um mal ˈrej]	*és un mal rei*	‘he is a bad king’
	Val. [reŋnal rej ˈsɔl]	*regna el rei Sol*	‘the Sun King reigns’
Intervocalic trill			
/ari/	Maj. [jəribə ŋˈgwaɲ]	*hi arriba enguany*	‘he/she arrives there this year’
	Val. [aɾa todz aˈriben]	*ara tots arriben*	‘they all arrive now’
/are/	Maj. [lə kazə ləˈreggl]	*la casa l’arregl*	‘I repair the house’
	Val. [ja pozab barez ðe ˈfusta]	*hi ha posat barres de fusta*	‘he/she has put wooden bars there’
/ara/	Maj. [unə rattʃə ˈbɔnə]	*una ratxa bona*	‘a run of good luck’
	Val. [una ratʃa ˈbɔna]		
Postconsonantal tap			
/pɾ/$_1$	Maj. [kompɾəl lə ˈtorə]	*compra’t la torre*	‘buy yourself the tower’
	Val. [kompɾal la ˈtore]		
/pɾ/$_2$	Maj. [lə pɾoəj lə ˈpopə]	*la proa i la popa*	‘the prow and the astern’
	Val. [la pɾoaj la ˈpopa]		
/bɾ/	Maj. [diw kə te ˈfeβɾə]	*diu que té febre*	‘he/she says that he/she is in a fever’
	Val. [diw ke te ˈfeβɾe]		
/gɾ/	Maj. [kəbəj ɣruˈʃut]	*cabell gruixut*	‘thick hair’
	Val. [kabeʎ ɣrujˈʃut]		
Intervocalic tap			
/eɾi/	Maj. [inʒəɾi ˈlikit]	*ingerí líquid*	‘he/she ingested liquid’
	Val. [indʒeɾi ˈlikit]		
/aɾa/	Maj. [sa bəɲaˈt aɾə]	*s’ha banyat ara*	‘he/she has taken a bath now’
	Val. [aɾa todz aˈriben]	*ara tots arriben*	‘they all arrive now’
/wɾe/	Maj. [ənzi kal ˈʒawɾə]	*ens hi cal jaure*	‘we must lie down there’
	Val. [el va vewɾej ˈʃir]	*el va veure eixir*	‘he/she saw him leave’
Preconsonantal rhotic			
/rp/	Val. [una mar ˈplana]	*una mar plana*	‘a calm sea’
/rb/	Val. [una mar ˈbɾava]	*una mar brava*	‘a stormy sea’
/rm/	Maj. [əsta ðə pərˈmis]	*està de permís*	‘he/she is on permission’
	Val. [esta ðe perˈmis]		
/rt/	Maj. [pɔrtə wm paʎ ˈʎark]	*porta un pal llarg*	‘he/she holds a long stick’
/rd/	Maj. [əmo tərˈða]	*amor tardà*	‘late love’
	Val. [una mar ˈðolsa]	*una mar dolça*	‘a pleasant sea’
/rn/$_1$	Maj. [um pəɾiʎ inˈtɛrn]	*un perill intern*	‘an internal danger’
/rn/$_2$	Maj. [əl forn ləsˈkombɾ]	*el forn, l’escombr*	‘I clean the oven with an oven broom’
/rl/	Maj. [parlə zulu ˈbe]	*parla zulú bé*	‘he/she speaks Zulu well’
/rs/	Val. [la mar ˈsanta]	*la mar santa*	‘the holy sea’
/rʃ/	Maj. [əz eʎ ki ˈmarʃə]	*és ell qui marxa*	‘he goes away’
/rk/	Val. [una mar kalˈma]	*una mar calmada*	‘a calm sea’
/rg/	Maj. [unə pladdʒə ˈʎarɣə]	*una platja llarga*	‘a long beach’
	Val. [una pladʒa ˈʎarɣa]		

Table 1. (continued)

Utterance-final rhotic			
/ir#/	Val. [el va vewɾej'ʃir]	*el va veure eixir*	'he/she saw him go out'
/er#/	Val. [amik trist i sin'ser]	*amic trist i sincer*	'a sad and sincere friend'
/ar#/$_1$	Val. [ez ðiw ɣas'par]	*es diu Gaspar*	'his name is Gaspar'
/ar#/$_2$	Val. [am vist el 'mar]	*han vist el mar*	'they have seen the sea'
/ɔr#/	Val. [i poza baretez 'ðɔr]	*hi posà barretes d'or*	'he/she put small golden bars there'

Syllable-final rhotics have been transcribed with the symbol [r] and a stress mark has been preposed to the syllable exhibiting sentence stress. The sequences /pɾ, rn, ar#/ have been coded with subscripts 1 and 2 since they were read in two different sentences.

[1]Name of a Catalan philosopher.

Table 2. List of sequences read by the Eastern Catalan speakers in phonetic transcription and in Catalan orthography

Preconsonantal rhotic			
/rt/	[mar 'taj]	*mar Thai*	'Thai sea'
/rn/	[far 'nazi]	*far nazi*	'Nazi lighthouse'
/rl/	[bar 'lat]	*bar lat*	'large bar'
/rs/	[ʎar 'santə]	*llar santa*	'holy home'
/rʎ/	[far 'ʎark]	*far llarg*	'long lighthouse'
/rʒ/	[bar 'ʒaβə]	*bar Java*	'bar Java'
/rk/	[bar 'kar]	*bar car*	'expensive bar'
Utterance-final rhotic			
/ar#/$_1$	[gad 'rar]	*gat rar*	'strange cat'
/ar#/$_2$	[aɲ 'kar]	*any car*	'expensive year'

Syllable-final rhotics have been transcribed with the symbol [r] and a stress mark has been preposed to the syllable exhibiting sentence stress. The sequence /ar#/ has been coded with subscripts 1 and 2 since it was read in two different sentences.

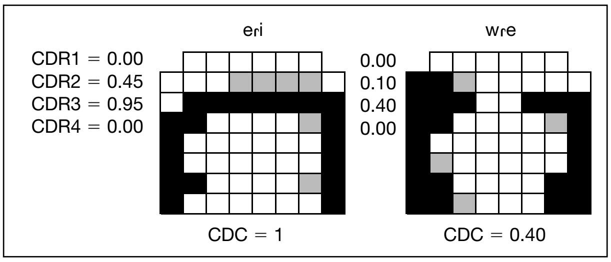

Fig. 1. Mean linguopalatal contact patterns for /eɾi/ (speaker N.D.) and /wɾe/ (speaker M.J.). Electrodes appear in black, gray or white depending on frequency of activation across repetitions, i.e. 80–100% (black), 40–80% (gray) and less than 40% (white). CDC and CDR indices for the four anterior rows of electrodes at the alveolar zone are given for each EPG pattern.

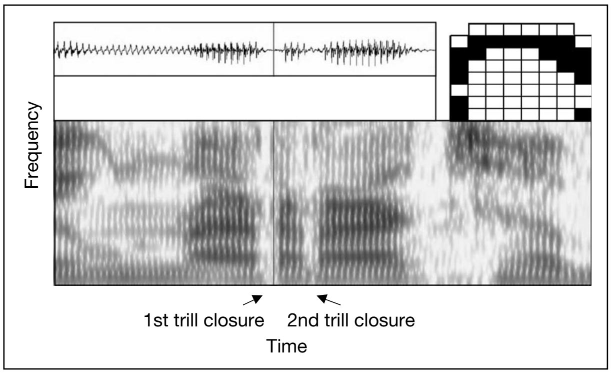

Fig. 2. Waveform, spectrographic and EPG displays for one token of the sequence [una ratʃa] *una ratxa* (speaker V.G.). The EPG contact configuration corresponds to the first closure period of the trill just where the cursor is located. The spectrogram frequency scale is 0–5 kHz.

by the onset or offset of voiced formant structure if the rhotic and the adjacent consonant were voiceless, or else by intensity and formant frequency discontinuities in case that voicing was present during the adjacent consonant and/or during the rhotic.

Contact patterns were measured and averaged at the frame exhibiting the alveolar closure or maximal alveolar constriction narrowing. If closure or maximal alveolar constriction occurred in two consecutive EPG contact frames, we selected the first frame if the two frames showed identical alveolar contact patterns or else the frame with the highest number of 'on' electrodes at the four central alveolar rows if the two consecutive EPG frames were not identical. As for utterance-initial trills, the representative EPG configuration was often taken to occur at the midpoint of a very long first or only contact period. In case there were no 'on' electrodes at the four central alveolar columns (e.g. for the sequence /eɾi/), we selected the EPG frame located at the midpoint of a minimal amplitude period determined on spectrographic displays.

Linguopalatal contact data were reduced using five indices applied to the only constriction phase of one-contact rhotics or to the first and second constriction phases of more complex rhotic productions. These indices were contact degree by columns or CDC, alveolar contact centrality or CCa, contact degree by rows or CDR, alveolar contact anteriority or CAa, and palatal contact size or Qp.

Constriction degree was evaluated using CCa [see Fontdevila et al., 1994] and CDC. CCa values increase as 'on' alveolar electrodes become more central. In order to calculate the CDC index, a value of 1 was assigned to the alveolar portion of each of the four central columns when one or more of its electrodes were activated. Otherwise, the value assigned to each column was 0. Means were calculated across columns for each token and the resulting CDC values were averaged across repetitions of each sequence. This index measure assigns correctly the same value to an EPG pattern showing activation of all 16 electrodes at the area of interest and to a pattern showing activation of a single electrode on each row within this area. This contact index is exemplified with means across tokens for /eɾi/ (speaker N.D.) and /wɾe/ (speaker M.J.) in the palatograms of figure 1. The corresponding CDC values are 1 (since CDC values for all repetitions also equalled 1) and 0.4 (given that the CDC values for the individual tokens were 0.0, 0.5, 0.5, 0.5 and 0.5), which is in agreement with differences in degree of central contact between the two EPG patterns.

Constriction location was computed using CAa [Fontdevila et al., 1994] and CDR. CAa values increase with the activation of more anterior electrodes. In our study this index was not necessarily indicative of place of articulation for rhotics since only utterance-initial and postconsonantal trills were produced with a complete closure in practically all sentence repetitions. The CDR index value for a given row is the percentage of activation for the four central electrodes on that row. In our study, CDR was computed separately for each of the four alveolar rows, i.e. CDR1, CDR2, CDR3 and

CDR4. CDR values were obtained for each token and then computed across repetitions of each sequence. The two EPG patterns of figure 1 report mean CDR values across repetitions for each row. Index values are higher at row 3 than at the other rows 1, 2 and 4, which is consistent with the fact that closure or constriction location occurs essentially at that row in the two patterns. Dorsopalatal contact size was evaluated using Qp by averaging the number of activated electrodes at the palatal zone over the maximal number of electrodes at that zone.

F1, F2 and F3 were measured on spectrographic displays at the same temporal point as the EPG indices or at the opening period for trills if formants were not visible during the constriction phase. Formant frequency measurements could not be taken for Valencian utterance-final rhotics since formant structure was absent in this case.

Devoicing was analyzed for utterance-initial, preconsonantal and utterance-final trills. Voicing for /#r/ was easily visible on spectrograms. The offset of the low amplitude pitch pulses for preconsonantal and utterance-final rhotics was determined from simultaneous inspection of spectrographic displays, the acoustic waveform, and the laryngographic signal when available. In order to obtain an estimate of the degree of consonant devoicing for /#r/ and /r#/, we calculated the ratio between the duration of the voicing period during the consonant (i.e. the interval between voicing onset and vowel onset for /#r/, and between vowel offset and voicing offset for /r#/) and closure duration (i.e. the interval between rhotic onset and vowel onset for /#r/, and between vowel offset and rhotic offset for /r#/).

For all /VɾV, CɾV, rC/ sequences in the story material, we computed the frequency of occurrence of cases of complete closure, incomplete closure or the absence of closure when there was complete contact, a narrow central channel or no contact at the four alveolar central columns, respectively. We also identified the row or rows exhibiting maximal central constriction and checked whether there was an epenthetic vowel element.

Articulatory and acoustic data on rhotics occurring in the same or comparable contextual conditions in the Majorcan and Valencian sentence material were subjected to statistical analysis using several ANOVAs with repeated measures, i.e. data on /ɾ/ and /r/ between vocalic segments (/eɾi, aɾa, wɾe, ari, are, ara/), on postconsonantal taps (/pɾ$_1$, bɾ, gɾ/), and on utterance-initial and postconsonantal trills (/#r, nr, lr/). The significance level was set at $p < 0.05$, and Bonferroni multiple comparisons tests were applied to significant main effects and interactions. Statistical tests on the intervocalic and /Cɾ/ data had 'vowel context' and 'dialect' (for the intervocalic condition) and 'consonant context' and 'dialect' (for the /Cɾ/ condition) as independent variables, and 'duration' for the entire tap or trill and for the first contact period of the trill, and 'CDC', 'CCa', 'CAa', 'Qpal', 'F1' and 'F2', as dependent variables. F3 data were left out since these formant frequency values were absent or not highly reliable a good number of times. ANOVAs on data for utterance-initial and postconsonantal trills were carried out separately for /#r/, /nr/ and /lr/, with 'dialect' as the independent variable and the same dependent variables referred to above.

3 Results

3.1 Trills

3.1.1 Utterance-Initial Position

Inspection of data for the individual speakers in table 3 reveals that utterance-initial trills are not always produced with two or more contacts, and that Valencian speakers may allow for more contacts than Majorcan speakers. As shown in table 4, the first (or only) contact exceeds 100 ms in both dialects, and the second and third contacts are about 15 ms long. The opening phase between the consecutive contacts in a two-contact trill is slightly longer than the second contact (20–50 ms). ANOVAs yielded a significantly longer first contact in Majorcan than in Valencian [$F(1, 44) = 4.16$, $p < 0.05$], but no dialect-dependent differences in entire trill duration.

Table 3. Percentage of occurrence of number of contacts 1 through 4 for the trill in utterance-initial, postconsonantal and intervocalic position, and for syllable-final rhotics before a consonant and utterance-finally

		#r				Cr			VrV			rC			r#			
		1	2	3	4	1	2	3	1	2	3	1	2	3	1	2	3	4
Majorcan	A.R.	80	20			30	70		26.7	73.3		100						
	B.M.	80	20			20	80		40	60		100						
	M.J.	20		40	40		50	50	6.7	93.3		100						
	N.D.	100				10	80	10		100		100						
	C.A.											100						
Valencian	J.M.	60	40				90	10		80	20	100			87.5	12.5		
	V.B.	100				10	70	20		66.7	33.3	97.5	2.5		100			
	M.S.		40	60			70	30		86.7	13.3	100			100			
	V.G.		60	40			100		6.7	93.3		100			100			
	A.V.	40	60			40	60			100		100			50	40	10	
Eastern Catalan	D.R.											84.8	15.2		2.9	28.5	65.7	2.9
	J.P.											81	19		32.4	58.8	8.8	
	J.S.											95	5		38	58.6	3.4	

Data are given for the individual speakers of Majorcan, Valencian and Eastern Catalan, but not for /#r, Cr, VrV/ sequences for speaker C.A., whose trills were uvular instead of alveolar.

Table 4. Duration, EPG contact index values and formant frequencies for the trill in the utterance-initial, postconsonantal and intervocalic positions

		Duration				EPG contact indices								Formants		
		1st closure	2nd closure	3rd closure	total	CDC	CCa	CAa	CDR1	CDR2	CDR3	CDR4	Qp	F1	F2	F3
Majorcan	#r	138.5	15.0	15.0	158.5	0.975	0.838	0.631	0.150	0.663	0.500	0.250	0.258	447.7	1,323.1	2,473.3
		37.17	*5.48*	*5.77*	*58.42*	*0.077*	*0.045*	*0.233*	*0.274*	*0.439*	*0.406*	*0.421*	*0.054*	*97.14*	*90.13*	*120.40*
	nr	21.0	15.0	15.0	65.0	0.975	0.842	0.674	0.188	0.663	0.450	0.263	0.289	522.4	1,297.6	2,269.3
		3.08	*6.18*	*5.48*	*22.59*	*0.077*	*0.052*	*0.233*	*0.291*	*0.431*	*0.441*	*0.425*	*0.066*	*103.89*	*121.43*	*203.10*
	lr	20.0	15.0		53.0	0.913	0.814	0.752	0.275	0.850	0.338	0.088	0.184	514.7	1,197.0	2,344.0
		9.73	*5.16*		*13.42*	*0.203*	*0.119*	*0.158*	*0.436*	*0.221*	*0.431*	*0.186*	*0.050*	*79.12*	*121.96*	*253.12*
	ari	17.5	16.8		53.5	0.750	0.744	0.533	0.013	0.550	0.538	0.013	0.281	478.0	1,481.0	2,546.0
		7.16	*10.57*		*14.96*	*0.281*	*0.170*	*0.196*	*0.056*	*0.402*	*0.374*	*0.056*	*0.044*	*63.54*	*204.11*	*118.25*
	are	17.0	15.6		48.5	0.875	0.775	0.628	0.150	0.650	0.488	0.025	0.230	527.4	1,305.3	2,483.3
		6.57	*5.12*		*13.09*	*0.236*	*0.138*	*0.258*	*0.262*	*0.447*	*0.367*	*0.077*	*0.031*	*55.86*	*91.86*	*118.27*
	ara	21.5	14.3		46.0	0.325	0.442	0.509	0.063	0.150	0.163	0.000	0.211	553.0	1,271.0	2,397.9
		13.09	*5.14*		*11.88*	*0.258*	*0.220*	*0.203*	*0.138*	*0.170*	*0.306*	*0.000*	*0.027*	*50.38*	*86.93*	*109.73*
Valencian	#r	112.0	16.0	16.0	144.4	1.000	0.866	0.652	0.160	0.720	0.660	0.140	0.229	528.7	1,403.5	2,229.1
		47.61	*5.07*	*5.48*	*41.24*	*0.000*	*0.036*	*0.197*	*0.297*	*0.370*	*0.438*	*0.298*	*0.055*	*87.14*	*115.94*	*244.85*
	nr	20.0	12.9	15.0	57.2	1.000	0.855	0.752	0.370	0.790	0.430	0.000	0.218	542.6	1,314.8	2,258.9
		6.45	*4.63*	*5.77*	*25.09*	*0.000*	*0.045*	*0.198*	*0.485*	*0.320*	*0.471*	*0.000*	*0.058*	*61.29*	*100.58*	*201.05*
	lr	18.4	17.1	15.0	63.2	1.000	0.861	0.724	0.300	0.790	0.510	0.050	0.200	530.0	1,272.5	2,212.7
		5.54	*9.55*	*7.07*	*17.96*	*0.000*	*0.038*	*0.196*	*0.408*	*0.359*	*0.465*	*0.204*	*0.053*	*43.74*	*141.40*	*212.25*
	ari	15.2	16.3	11.4	62.4	0.480	0.563	0.554	0.190	0.280	0.180	0.000	0.244	494.4	1,375.2	2,316.8
		5.86	*5.76*	*3.78*	*18.77*	*0.322*	*0.245*	*0.244*	*0.391*	*0.220*	*0.234*	*0.000*	*0.060*	*46.38*	*96.14*	*200.89*
	are	17.2	16.0	20.0	62.0	0.960	0.826	0.639	0.130	0.740	0.520	0.000	0.211	544.0	1,345.6	2,295.2
		6.14	*5.77*		*10.41*	*0.094*	*0.066*	*0.177*	*0.332*	*0.310*	*0.484*	*0.000*	*0.056*	*47.96*	*134.72*	*146.66*
	ara	15.2	13.6	10.0	55.2	0.550	0.536	0.529	0.190	0.290	0.170	0.000	0.190	580.8	1,284.2	2,240.0
		5.10	*4.90*	*0.00*	*9.18*	*0.395*	*0.284*	*0.282*	*0.391*	*0.277*	*0.304*	*0.000*	*0.053*	*61.43*	*108.90*	*166.57*

Data correspond to averages across repetitions and speakers of Majorcan and Valencian. Standard deviations are given in italics except for cases where a single token was computed. The sequences /ari, are, ara/ are realized [əri, əre, əra] in Majorcan.

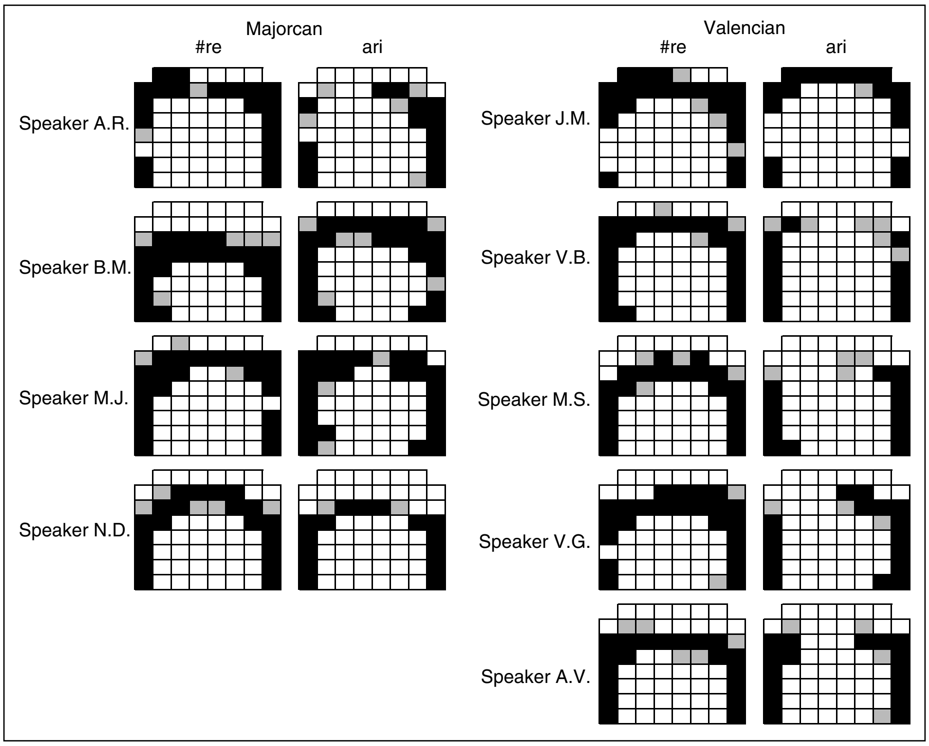

Fig. 3. Mean linguopalatal contact patterns for the trill in the sequences /#re/ and /ari/ according to all Majorcan and Valencian speakers.

One-contact /#r/ may show a burst followed by either a 20- to 40-ms steady-state approximant period immediately before the following vowel or a short frication noise, but this is generally not the case for multiple-contact /#r/. As pointed out by Ladefoged and Maddieson [1996, p. 219], this approximant period occurs while the tongue is raised but not held close enough to the upper surface of the mouth for trilling to be sustained. The first or only contact of an utterance-initial trill may be completely voiceless most of the time, completely or partly voiceless, or partly voiceless and partly voiced, depending on speaker. The short contact and opening periods following the first contact in multiple-contact trills are generally voiced. Percentages of voicing over overall rhotic duration across speakers are less in Majorcan (mean = 0.29, SD = 0.26) than in Valencian (mean = 0.47, SD = 0.21).

Majorcan and Valencian speakers agree in showing a complete closure in practically all tokens of /#r/ independently of number of contacts (see EPG patterns for /#re/ in fig. 3). Accordingly, the corresponding CDC values in table 4 equal 1 or are close to 1. Values for the EPG contact indices reflecting constriction degree in the table, i.e. CDC and CCa, are slightly higher in Valencian than in Majorcan, and the dialect-dependent CCa difference achieves significance [$F(1, 44) = 5.56$, $p < 0.02$]. The second contact also exhibits higher CDC and CCa values in Valencian, and is usually occluded for all Valencians but not for all Majorcans.

Dialects do not differ significantly in CAa and thus, in place of articulation, for /#r/. They exhibit relatively high CDR2 and CDR3 values meaning that closure location occurs at row 2 and, less so, at row 3 (table 4). Qp values are nonsignificantly higher in Majorcan vs. Valencian, and both dialects differ significantly in F1 and F2 for Valencian > Majorcan [$F(1, 35) = 6.61$, $p < 0.05$; $F(1, 35) = 4.64$, $p < 0.05$] and in F3 for Majorcan > Valencian.

3.1.2 Postconsonantal Position

Postconsonantal trills deviate from utterance-initial trills mostly in overall number of contacts, constriction fronting and voicing (tables 3, 4). They exhibit two extremely short contacts as a general rule, and do not differ significantly in overall duration or in the duration of the first closure period as a function of dialect. CAa, CDR1 and CDR2 values reveal that trills may be more anterior postconsonantally than utterance-initially. Generally speaking, postconsonantal trills are not followed by an approximant element, are fully voiced and may exhibit a burst with some friction release.

Other phonetic properties, i.e. degree of central constriction, linguopalatal contact size and formant frequency, coincide with those for /#r/. Postconsonantal trills are produced with a complete closure and are more constricted in Valencian than in Majorcan according to statistical results for the CDC index data [$F(1, 44) = 4.66$, $p < 0.05$]. CDC and CCa values for the second contact are also higher in Valencian. ANOVAs yielded no significant dialect-dependent effects for Qp, and for the formant frequencies which varied in the progression Valencian > Majorcan (F1, F2) and Majorcan > Valencian (F3).

3.1.3 Intervocalic Position

Intervocalic trills are generally produced with two contacts of a similar duration though one and three contacts are also possible (table 3). Trills were significantly longer for /ari/ than for /ara, are/ [$F(1, 129) = 3.41$, $p < 0.05$], which is most likely related to the difficulty involved in making a trill next to a high front vowel presumably since the two segments involve antagonistic gestures, i.e. tongue dorsum lowering and backing for the trill and tongue dorsum raising and fronting for the vowel. Analogously to /#r/, Valencian exceeds Majorcan in overall consonant duration [$F(1, 129) = 20.50$, $p < 0.001$] and in number of contacts (see also table 3), while the first or only contact is significantly longer in Majorcan than in Valencian, i.e. mean = 18.7 ms vs. mean = 15.9 ms [$F(1, 129) = 4.55$, $p < 0.05$]. Intervocalic trills are voiced throughout. A 20- to 30-ms-long approximant element is generally absent but may occur after one-contact trills in the story data.

In addition to not always being longer than the following contacts, the first contact period is not always entirely closed. As shown in table 4, CDC and CCa values are lower for intervocalic trills than for trills in the other syllable-initial positions, meaning that the consonant is produced with less central contact (compare the EPG patterns for /#re/ and /ari/ in figure 3 in this respect). CDC yielded a significant effect of ‘vowel context’ for /are/ > /ari/ > /ara/ where a decrease in constriction degree for the rhotic may be attributed to gestural antagonism next to /i/ in the sequence /ari/ and to undershoot next to /a/ in the sequence /ara/ [$F(2, 129) = 32.87$, $p < 0.001$]. Moreover both CDC and CCa yielded no significant effect of ‘dialect’ but a significant ‘dialect’ × ‘vowel context’ interaction associated with a higher value for /ari/ and a lower value for /ara/ in Majorcan vs. Valencian [$F(2, 129) = 9.08$, $p < 0.001$ for CDC;

$F(2, 129) = 5.87$, $p < 0.01$ for CCa]. Data for the second contact period are very similar to those just referred to, i.e. CDC decreases in the progression /are/ > /ari, ara/, and is higher for /ari/ and lower for /ara/ in Majorcan vs. Valencian.

Analogously to /#r/, intervocalic trills exhibit a similar constriction location in both dialects. Indeed, CAa yielded no significant dialect-dependent effect, and constriction location occurs at rows 2 or at 2–3 and is somewhat more anterior than that for /#r/ for some speakers (B.M., J.M., V.G., A.V.).

Intervocalic /r/ involves less overall tongue contact than /#r/ though the presence of a low vowel immediately before the trill may account completely or partially for this difference, i.e. Qp and F2 values are lower for /are, ara/ than for /#r/ across speakers and for most individual speakers. As expected, Qp and F2 decrease for /ari/ > /ara, are/ [$F(2, 129) = 19.31$, $p < 0.001$; $F(2, 127) = 16.42$, $p < 0.001$], and F1 varies in the opposite progression /ara/ > /are/ > /ari/ [$F(2, 127) = 24.75$, $p < 0.001$]. Qp and F2 turned out to be significantly higher in Majorcan than in Valencian [$F(2, 129) = 9.49$, $p < 0.05$; $F(2, 127) = 4.19$, $p < 0.05$ for /ari/ only], while F1 conforms to the opposite trend [$F(1, 127) = 4.58$, $p < 0.05$]. F3 shows no consistent position-dependent differences and is higher in Majorcan (2,398–2,546 Hz) than in Valencian (2,240–2,317 Hz).

3.1.4 Summary

Utterance-initial trills may be produced with one to three contacts depending on speaker, while intervocalic and postconsonantal trills exhibit two contacts as a general rule though one and three contact realizations are also possible. The first contact is longest for /#r/ but not necessarily for /Cr, VrV/, and fully occluded for /#r, Cr/ but not always for /VrV/. Utterance-initial trills may undergo partial devoicing and are followed by an approximant period or a burst mostly in one-contact productions; in comparison to intervocalic trills, they may involve more tongue contact and a higher F2, and may be more retracted. Devoicing and a burst may also occur in /Cr/ clusters, and there may be vowel coarticulation in intervocalic position.

Trills are centroalveolar and thus, more anterior in Majorcan and Valencian than in Eastern Catalan (see section 1.1). In comparison to Majorcan trills, Valencian trills show more contacts and a shorter first contact, which is less prone to devoice utterance-initially. Moreover, they are more constricted and have a higher F2 utterance-initially and postconsonantally, but often exhibit a wider constriction, less tongue contact and a lower F2 intervocalically. These position-dependent differences suggest that, compared to Majorcan trills, Valencian trills are more reinforced in the strong /#r, Cr/ conditions and may be more reduced in the weaker intervocalic position.

3.2 Taps

3.2.1 Postconsonantal Position

Table 5 shows that postconsonantal taps are significantly shorter after voiceless vs. voiced stops [$F(2, 144) = 15.99$, $p < 0.001$], and in Valencian vs. Majorcan with means between 13–24 ms and 18–29 ms, respectively [$F(1, 144) = 11.33$, $p < 0.001$]. They may trigger the insertion of an epenthetic vowel element, which occurs systematically in Valencian and about 75% of the time in Majorcan. This vocalic segment is nonsignificantly longer in Valencian than in Majorcan, and significantly longer in the voiced clusters /bɾ, gɾ/ than in the voiceless cluster /pɾ/, where it is absent for the Majorcan speakers A.R. and B.M. [$F(2, 125) = 13.55$, $p < 0.001$]. In the story data, vowel insertion also occurs more often in Valencian, and may show up not only in /Cɾ/ sequences with heterorganic labial and velar stops but also in the (quasi-)homorganic clusters /tɾ, dɾ/. Occasionally, clusters with a voiceless consonant exhibit two contacts

Table 5. Duration for the tap and the epenthetic vowel, EPG contact index values for the tap and formant frequencies for the tap in the postconsonantal and intervocalic positions

		Duration		EPG contact indices								Formants		
		tap	vowel	CDC	CCa	CAa	CDR1	CDR2	CDR3	CDR4	Qp	F1	F2	F3
Majorcan	pɾa	20.0	25.7	0.460	0.479	0.241	0.000	0.060	0.400	0.100	0.219	460.0	1,374.8	2,105.5
		9.57	*5.35*	*0.386*	*0.308*	*0.164*	*0.000*	*0.181*	*0.402*	*0.191*	*0.068*	*58.61*	*115.56*	*200.87*
	pɾo	17.6	24.5	0.500	0.536	0.346	0.000	0.140	0.360	0.090	0.224	445.7	1,316.0	1,915.2
		7.23	*12.34*	*0.375*	*0.246*	*0.187*	*0.000*	*0.289*	*0.331*	*0.189*	*0.040*	*40.07*	*122.20*	*196.36*
	bɾe	27.6	39.6	0.570	0.614	0.472	0.000	0.380	0.320	0.100	0.255	409.2	1,640.0	2,510.0
		10.52	*15.13*	*0.385*	*0.228*	*0.181*	*0.000*	*0.376*	*0.335*	*0.204*	*0.036*	*86.27*	*152.91*	*183.01*
	gɾu	29.2	42.8	0.850	0.765	0.639	0.060	0.690	0.330	0.020	0.431	351.2	1,315.6	2,227.7
		8.62	*10.61*	*0.204*	*0.078*	*0.162*	*0.149*	*0.348*	*0.336*	*0.069*	*0.073*	*35.63*	*148.97*	*137.49*
	eɾi	32.8		0.440	0.507	0.434	0.020	0.220	0.340	0.010	0.360	380.0	1,816.7	2,623.3
		11.73		*0.363*	*0.244*	*0.189*	*0.069*	*0.325*	*0.345*	*0.050*	*0.066*	*50.04*	*168.23*	*108.85*
	aɾa	29.6		0.880	0.778	0.679	0.150	0.750	0.330	0.060	0.251	560.8	1,633.6	2,617.4
		9.78		*0.218*	*0.131*	*0.172*	*0.250*	*0.354*	*0.366*	*0.166*	*0.037*	*147.73*	*131.75*	*127.39*
	wɾe	33.6		0.770	0.711	0.449	0.000	0.300	0.670	0.200	0.356	372.5	1,447.8	2,597.8
		8.60		*0.314*	*0.199*	*0.184*	*0.000*	*0.415*	*0.373*	*0.306*	*0.044*	*53.34*	*200.61*	*169.27*
Valencian	pɾa	15.6	31.7	0.850	0.746	0.455	0.000	0.410	0.580	0.020	0.183	456.0	1,310.5	2,065.0
		7.12	*7.02*	*0.228*	*0.141*	*0.159*	*0.000*	*0.426*	*0.437*	*0.069*	*0.077*	*86.96*	*125.50*	*188.72*
	pɾo	13.2	35.2	0.870	0.736	0.571	0.090	0.620	0.340	0.040	0.211	432.2	1,193.7	1,715.4
		4.76	*10.46*	*0.261*	*0.169*	*0.204*	*0.238*	*0.409*	*0.414*	*0.118*	*0.054*	*60.25*	*96.62*	*273.39*
	bɾe	22.8	43.2	0.840	0.742	0.783	0.370	0.690	0.100	0.000	0.241	470.0	1,565.0	2,326.7
		5.42	*8.52*	*0.314*	*0.203*	*0.151*	*0.415*	*0.333*	*0.239*	*0.000*	*0.068*	*74.10*	*138.33*	*215.80*
	gɾu	24.4	42.0	0.750	0.698	0.644	0.230	0.600	0.250	0.000	0.320	332.5	1,198.0	2,322.5
		8.70	*11.55*	*0.402*	*0.255*	*0.229*	*0.408*	*0.415*	*0.323*	*0.000*	*0.072*	*51.01*	*76.20*	*205.25*
	eɾi	31.6		0.270	0.380	0.640	0.150	0.120	0.000	0.000	0.376	348.8	1,847.2	2,545.0
		6.88		*0.322*	*0.229*	*0.222*	*0.250*	*0.179*	*0.000*	*0.000*	*0.038*	*40.86*	*110.59*	*123.04*

aɾa	18.0	0.630	0.604	0.440	0.000	0.470	0.260	0.050	0.168	588.0	1,440.0	2,373.3
	7.07	*0.409*	*0.311*	*0.210*	*0.000*	*0.429*	*0.378*	*0.125*	*0.078*	*74.76*	*94.36*	*175.08*
wɾe	18.8	0.730	0.685	0.621	0.170	0.590	0.180	0.030	0.286	430.5	1,430.9	2,042.9
	5.26	*0.374*	*0.245*	*0.238*	*0.286*	*0.414*	*0.357*	*0.110*	*0.055*	*60.87*	*79.22*	*325.14*

Data correspond to averages across repetitions and speakers of Majorcan and Valencian. Standard deviations are given in italics. The sequences /pɾa, bɾe, eɾi, aɾa, wɾe/ are realized [pɾə, bɾə, əɾi, aɾə, wɾə] in Majorcan.

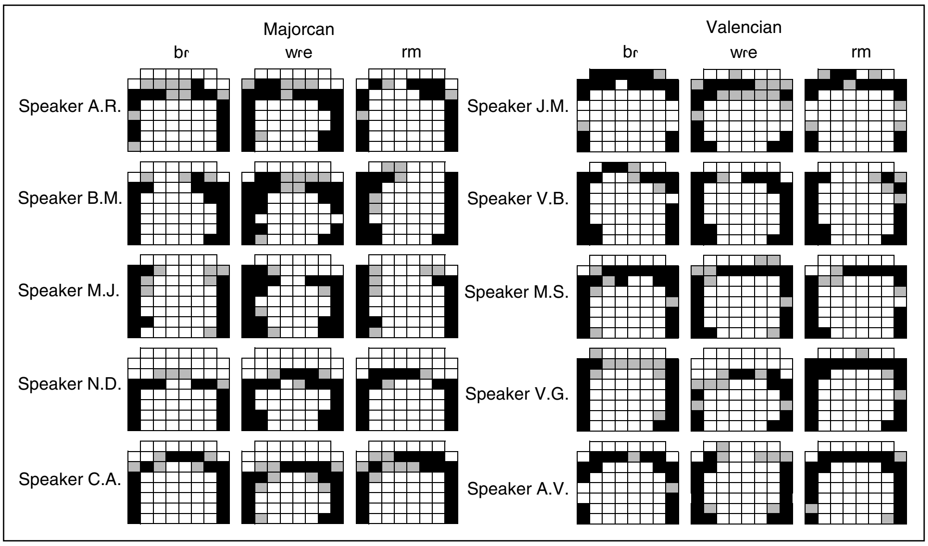

Fig. 4. Mean linguopalatal contact patterns for the tap and the preconsonantal rhotic in the sequences /bɾ, wɾe, rm/ according to all Majorcan and Valencian speakers.

(/pɾi, pɾe/) and some frication with possible partial or complete devoicing (/pɾi, pɾe, tɾ, kɾi/), and those with a voiced consonant are implemented through some lateral but no central tongue contact (/gɾ/).

Postconsonantal taps are more constricted in Valencian than in Majorcan, as revealed by significantly higher CDC and CCa values in the former dialect [$F(1, 144) = 12.04$, $p < 0.001$ for CDC; $F(1, 144) = 9.65$, $p < 0.01$ for CCa]. Moreover, ANOVAs yielded a significant 'consonant context' × 'dialect' interaction indicating that, as shown by the EPG patterns for /bɾ/ in figure 4, those dialect-dependent index differences hold essentially in labial clusters [$F(2, 144) = 7.51$, $p < 0.001$ for CDC; $F(2, 144) = 7.59$, $p < 0.001$ for CCa].

According to the CDR values, place of articulation may be more retracted in Majorcan than in Valencian. CAa also yielded a significant effect of 'dialect' and a significant 'consonant context' × 'dialect' interaction associated with differences in constriction fronting for Valencian > Majorcan in labial clusters [$F(1, 144) = 37.53$, $p < 0.001$; $F(2, 144) = 9.81$, $p < 0.001$]. Qp and F2 turned out to be significantly higher in Majorcan than in Valencian [$F(1, 144) = 24.05$, $p < 0.001$; $F(1, 125) = 17.25$, $p < 0.001$], and F3 values conform to the same dialect-dependent trend.

3.2.2 Intervocalic Position

As shown in table 5, intervocalic taps are as short as postconsonantal taps, i.e. mean durations across dialects range between 18 and 34 ms. ANOVAs on tap duration yielded a significant effect of 'vowel context' for /eɾi/ > /aɾa, wɾe/, a significant effect of 'dialect', and a significant 'vowel context' × 'dialect' interaction for Majorcan > Valencian in the sequences /aɾa, wɾe/ [$F(2, 144) = 12.99$, $p < 0.001$; $F(1, 144) = 44.05$,

$p < 0.001$; $F(2, 144) = 8.77$, $p < 0.001$]. Analogous dialect-dependent differences are available for the story data: taps are often longer in Majorcan than in Valencian, i.e. about 25 ms for speakers B.M. and C.A., about 20 ms for A.R., N.D., J.M. and M.J., and about 15 ms for M.S. and V.G.

Values for the EPG indices related to constriction degree, i.e. CDC and CCa, vary significantly in the progression /aɾa, wɾe/ > /eɾi/, which may be in line with the difficulty involved in closure formation for taps next to front vowels for reasons pointed out for trills in section 3.1.2 [$F(2, 144) = 22.94$, $p < 0.001$ for CDC; $F(2, 144) = 19.36$, $p < 0.001$ for CCa]. The two index values are significantly higher in Majorcan than in Valencian meaning that, differently from /Cɾ/ sequences, intervocalic taps are less constricted in the latter dialect [$F(1, 144) = 7.68$, $p < 0.01$ for CDC; $F(1, 144) = 8.20$, $p < 0.01$ for CCa]. This dialect-dependent difference shows up for /wɾe/ in the EPG patterns of figure 4, and is most obvious for /aɾa/ according to CDC values (0.88 in Majorcan, 0.63 in Valencian). Data from the story material agree with those just given in that complete and incomplete closure occurs less frequently in Valencian than in Majorcan (15.6 vs. 28.7%; 37.8 vs. 57.8%), while lack of central contact prevails in the former dialect vs. the latter (46.5 vs. 18.4%).

Place of articulation for the intervocalic tap does not differ much from that for /Cɾ/ sequences. According to the CDR and CAa data for Valencian in table 5, maximal constriction takes place at row 2 in the sequences /aɾa, wɾe/ and at the more anterior rows 1 and 2 in the sequence /eɾi/. In Majorcan, on the other hand, the tap is articulated basically at rows 2 and 3 for /eɾi/, at row 2 for /aɾa/ and at row 3 for /wɾe/. Therefore, the tap happens to be more anterior in Valencian than in Majorcan when adjacent to non-low vowels (see also EPG patterns for /wɾe/ in fig. 4).

Data on dorsopalatal contact and formant frequency are also in agreement with the /Cɾ/ scenario to a large extent. ANOVAs yielded a significant effect of 'vowel context' for /eɾi/ > /wɾe/ > /aɾa/ in the case of Qp [$F(2, 144) = 109.17$, $p < 0.001$], for /eɾi/ > /aɾa/ > /wɾe/ in the case of F2 [$F(2, 137) = 105.63$, $p < 0.001$] and for /aɾa/ > /eɾi, wɾe/ in the case of F1 [$F(2, 127) = 78.60$, $p < 0.001$]. There was also a main effect of 'dialect' and a significant 'vowel context' × 'dialect' interaction for Majorcan > Valencian in the sequences /aɾa, wɾe/ in the case of Qp [$F(1, 144) = 25.85$, $p < 0.001$; $F(2, 144) = 12.05$, $p < 0.001$] and in the sequence /aɾa/ in the case of F2 [$F(1, 137) = 6.81$, $p < 0.01$; $F(2, 137) = 9.01$, $p < 0.001$]. F1 turned out to be significantly higher for Valencian vs. Majorcan in the sequences /aɾa, wɾe/ [$F(2, 127) = 3.74$, $p < 0.05$], and mean F3 frequency ranges for Majorcan exceeded those for Valencian (2,617–2,623 Hz, 2,043–2,545 Hz).

As expected, the tap is articulated with more dorsopalatal contact and shows a higher F2 than the trill in both dialects (tables 4, 5): mean F2 ranges amount to 1,448–1,817 Hz for the tap and 1,271–1,481 Hz for the trill in Majorcan, and to 1,430–1,847 Hz and 1,284–1,375 Hz in Valencian; mean Qp ranges are 0.25–0.36 for /ɾ/ and 0.21–0.28 for /r/ in Majorcan, and 0.17–0.38 and 0.19–0.24 in Valencian.

3.2.3 Summary

The intervocalic tap is produced with more dorsopalatal contact and a higher F2 than the trill and, contrary to Eastern Catalan (see section 1.1), there are no apparent differences in constriction location between the two rhotics in Valencian and Majorcan. Taps are shorter and more constricted in back vs. front vowel contexts, and show differences in dorsopalatal contact size or Qp, F2 and F1 as a function of variations in tongue dorsum raising and fronting, labiality and oral opening in the contextual vowels. Changes in manner of articulation for taps in /Cɾ/ sequences appear to be contextually determined, i.e. postconsonantal taps may undergo trilling, assibilation and devoicing in clusters with a voiceless stop and a high front vowel, and extreme undershoot in voiced velar clusters.

In comparison to Majorcan, Valencian intervocalic taps are often shorter (mostly so in back vowel contexts), more anterior (in the sequences /eɾi, wɾe/), less constricted, less palatal (/aɾa, wɾe/), and have a lower F2 (/aɾa/), a higher F1 (/aɾa, wɾe/) and a lower F3. A similar but not identical scenario holds for postconsonantal taps: the Valencian rhotic is also shorter, more anterior and less palatal, and exhibits a lower F2 and F3, but a narrower, not wider alveolar constriction in labial consonant contexts. Another dialect-dependent difference is associated with the epenthetic vowel which is inserted more frequently and is somewhat longer in Valencian than in Majorcan.

3.3 Syllable-Final Rhotics

3.3.1 Preconsonantal Position

Preconsonantal rhotics involve one contact in Valencian and Majorcan, and mostly one contact but also two contacts in Eastern Catalan (table 3). As shown in table 6, they are shorter in Valencian (14–18 ms) than in Majorcan (18–29 ms) and longest in Eastern Catalan (20–35 ms), which appears to be in accordance with descriptive data stating that syllable-final rhotics are realized as taps in the two former dialects and as trills in the latter. Preconsonantal rhotics are always voiced in Valencian, in Majorcan and for some Eastern Catalan speakers (for J.P. and J.S.) but not for others (i.e. for D.R. whose rhotics are kept voiced before voiced /n, l, ʎ/ and become voiceless before voiceless /t, s, k/).

Analogously to /Cɾ/ clusters, vowel insertion takes place in /rC/ sequences whether the two consonants are produced at the same location or there is constriction motion from C1 to C2. Vowel epenthesis also occurs more often in Valencian than in Majorcan, i.e. 96 vs. 74% of the time (frequency of occurrence in Eastern Catalan is 86%). Moreover, there is a trend for the duration of the inserted vowel to be inversely related to rhotic duration, i.e. the vowel is longer in Valencian (24–60 ms) than in Majorcan (18–47 ms) and in Eastern Catalan (27–45 ms). According to the story data, the phonetic implementation of vowel epenthesis depends on dialect and cluster, i.e. it may be present in Majorcan and Valencian for /rk/, it is generally absent in Majorcan and present in Valencian for /rt, rd/, and is generally absent in both dialects for /rn, rl, rs/. This scenario reveals that vowel insertion is favored in heterorganic consonant clusters and disfavored in sequences where C2 is (quasi-)homorganic with the rhotic. Regarding the consonant sequences with a dental stop, the Majorcan subjects may show some frication during a completely occluded rhotic and a very brief oral opening or frication-like interval between the two consonants of the cluster.

CDC values indicate that the preconsonantal rhotic is more constricted in Valencian than in Majorcan and Eastern Catalan (see EPG patterns for /rm/ in fig. 4). According to table 6, CDC equals or exceeds 0.8 in six out of seven clusters in Valencian, in three clusters in Eastern Catalan and in no clusters in Majorcan. Mean CCa ranges also decrease in the progression Valencian (0.74–0.84) > Majorcan (0.58–0.74), Eastern Catalan (0.58–0.78).

Catalan dialects differ in place of articulation for preconsonantal /r/ in the progression Valencian > Majorcan > Eastern Catalan. In light of CDR values, constriction location takes place esentially at row 2 in the first dialect, at rows 2–3 in the second and at rows 3–4 in the third. Mean CAa ranges are in agreement with those CDR data, i.e. 0.56–0.77 (Valencian) > 0.43–0.65 (Majorcan) > 0.17–0.42 (Eastern).

Table 6. Duration for the rhotic and the epenthetic vowel, EPG contact index values for the rhotic and formant frequencies for the rhotic in preconsonantal and utterance-final position

		Duration					EPG contact indices								Formants		
		1st closure	2nd closure	3rd closure	total	vowel	CDC	CCa	CAa	CDR1	CDR2	CDR3	CDR4	Qp	F1	F2	F3
Majorcan	rm	29.2			29.2	30.0	0.620	0.649	0.548	0.060	0.390	0.350	0.030	0.275	432.0	1,534.4	2,626.0
		12.22			*12.22*	*10.29*	*0.354*	*0.227*	*0.178*	*0.149*	*0.369*	*0.402*	*0.083*	*0.049*	*46.19*	*173.83*	*150.52*
	rt	18.8			18.8	17.6	0.700	0.710	0.446	0.000	0.300	0.490	0.310	0.264	530.0	1,239.2	2,575.7
		9.27			*9.27*	*7.68*	*0.306*	*0.222*	*0.170*	*0.000*	*0.306*	*0.364*	*0.397*	*0.027*	*116.77*	*98.23*	*118.31*
	rd	27.1			27.1	42.7	0.625	0.623	0.653	0.125	0.490	0.125	0.000	0.272	484.0	1,510.0	2,762.2
		11.60			*11.60*	*11.00*	*0.369*	*0.221*	*0.156*	*0.245*	*0.407*	*0.233*	*0.000*	*0.047*	*47.89*	*199.39*	*112.00*
	rn	21.4			21.4	38.6	0.605	0.660	0.510	0.132	0.368	0.276	0.053	0.258	675.0	1,755.0	2,475.0
		10.27			*10.27*	*18.34*	*0.292*	*0.177*	*0.248*	*0.281*	*0.385*	*0.287*	*0.105*	*0.075*	*30.00*	*52.60*	*52.60*
	rl	18.0			18.0	32.7	0.733	0.740	0.522	0.067	0.450	0.433	0.033	0.235	435.0	1,240.0	2,732.0
		10.14			*10.14*	*15.34*	*0.320*	*0.165*	*0.172*	*0.148*	*0.403*	*0.427*	*0.088*	*0.029*	*30.00*	*77.97*	*122.15*
	rʃ	28.8			28.8	38.3	0.480	0.577	0.432	0.000	0.220	0.330	0.110	0.295	490.0	1,652.5	2,540.0
		13.61			*13.61*	*11.69*	*0.314*	*0.210*	*0.188*	*0.000*	*0.282*	*0.312*	*0.229*	*0.091*	*71.93*	*163.93*	*171.05*
	rg	25.6			25.6	47.2	0.560	0.632	0.478	0.210	0.350	0.230	0.070	0.270	445.7	1,708.6	2,636.7
		11.58			*11.58*	*11.00*	*0.370*	*0.261*	*0.325*	*0.366*	*0.415*	*0.346*	*0.135*	*0.060*	*37.80*	*68.17*	*50.20*
Valencian	rp	17.8			17.8	24.3	0.989	0.834	0.682	0.109	0.946	0.380	0.000	0.189	620.0		
		5.2			*5.2*	*9.5*	*0.052*	*0.048*	*0.117*	*0.248*	*0.105*	*0.405*	*0.000*	*0.055*			
	rb	16.4			16.4	32.1	0.970	0.817	0.767	0.310	0.870	0.200	0.000	0.184		1,393.3	
		4.9			*4.9*	*9.3*	*0.110*	*0.084*	*0.140*	*0.410*	*0.241*	*0.339*	*0.000*	*0.057*		*75.7*	
	rm	16.8			16.8	37.2	0.820	0.728	0.730	0.200	0.780	0.080	0.000	0.258	458.1	1,607.3	2,486.7
		6.3			*6.3*	*7.4*	*0.335*	*0.201*	*0.130*	*0.289*	*0.341*	*0.187*	*0.000*	*0.067*	*51.7*	*129.8*	*169.5*
	rd	15.8			15.8	35.8	0.938	0.818	0.642	0.156	0.760	0.396	0.000	0.190	510.0	1,282.9	2,420.0
		5.0			*5.0*	*8.8*	*0.169*	*0.103*	*0.181*	*0.328*	*0.350*	*0.442*	*0.000*	*0.062*	*42.4*	*49.6*	*169.7*
	rs	16.8			16.8	25.5	0.980	0.837	0.667	0.200	0.790	0.460	0.000	0.224	650.0	1,470.0	2,446.7
		6.3			*6.3*	*7.6*	*0.069*	*0.048*	*0.178*	*0.408*	*0.303*	*0.431*	*0.000*	*0.060*	*32.9*	*77.7*	*251.7*
	rk	14.0			14.0	34.4	0.760	0.679	0.562	0.070	0.570	0.270	0.000	0.191	651.1	1,376.0	2,333.3
		5.0			*5.0*	*7.7*	*0.334*	*0.221*	*0.179*	*0.245*	*0.385*	*0.408*	*0.000*	*0.049*	*75.2*	*82.2*	*199.5*
	rg	17.6			17.6	59.6	0.800	0.739	0.684	0.200	0.650	0.170	0.000	0.199	600.0	1,403.3	2,300.0
		5.2			*5.2*	*9.3*	*0.315*	*0.186*	*0.184*	*0.375*	*0.389*	*0.329*	*0.000*	*0.046*	*64.3*	*66.2*	*232.7*
	ar# (1)	19.2	10.0		20.8	103.8	0.650	0.629	0.641	0.120	0.580	0.100	0.000	0.220			
		8.8			*12.1*	*27.8*	*0.354*	*0.219*	*0.157*	*0.307*	*0.336*	*0.260*	*0.000*	*0.072*			

Table 6. (continued)

		Duration					EPG contact indices								Formants		
		1st closure	2nd closure	3rd closure	total	vowel	CDC	CCa	CAa	CDR1	CDR2	CDR3	CDR4	Qp	F1	F2	F3
	ar# (2)	22.5	18.3	20.0	41.7	104.7	0.917	0.795	0.691	0.167	0.823	0.260	0.000	0.198			
		15.7	*7.5*		*35.8*	*29.1*	*0.159*	*0.090*	*0.134*	*0.343*	*0.281*	*0.350*	*0.000*	*0.055*			
	ir#	36.0			36.0	89.0	0.510	0.577	0.623	0.180	0.360	0.000	0.000	0.343			
		17.1			*17.1*	*21.3*	*0.334*	*0.248*	*0.233*	*0.311*	*0.307*	*0.000*	*0.000*	*0.074*			
	er#	23.0			23.0	93.5	0.488	0.583	0.687	0.250	0.313	0.013	0.000	0.283			
		11.3			*11.3*	*28.0*	*0.329*	*0.207*	*0.191*	*0.406*	*0.242*	*0.056*	*0.000*	*0.061*			
	ɔr#	18.8	23.3	40.0	38.4	98.5	0.870	0.757	0.629	0.190	0.620	0.350	0.010	0.203			
		7.3	*8.2*		*34.7*	*24.3*	*0.261*	*0.163*	*0.206*	*0.391*	*0.403*	*0.395*	*0.050*	*0.054*			
Eastern Catalan	rt	20.0			20.0	38.0	0.750	0.732	0.286	0.000	0.045	0.705	0.636	0.259	513.3	1,333.3	2,266.7
		5.00			*5.00*	*12.52*	*0.354*	*0.254*	*0.133*	*0.000*	*0.151*	*0.384*	*0.259*	*0.015*	*128.58*	*80.83*	*172.43*
	rn	21.4	21.7		34.1	26.8	0.614	0.578	0.170	0.000	0.000	0.432	0.614	0.284	640.0	1,290.0	2,260.0
		5.05	*7.64*		*20.35*	*11.02*	*0.452*	*0.358*	*0.126*	*0.000*	*0.000*	*0.434*	*0.393*	*0.038*		*155.56*	
	rl	23.6			23.6	27.7	0.818	0.754	0.222	0.000	0.045	0.523	0.682	0.273	480.0	1,166.7	
		9.51			*9.51*	*9.32*	*0.298*	*0.253*	*0.141*	*0.000*	*0.101*	*0.395*	*0.318*	*0.037*	*20.00*	*80.83*	
	rs	22.0	17.5		30.5	41.0	0.800	0.754	0.417	0.050	0.300	0.675	0.375	0.263	500.0	1,380.0	2,366.7
		8.56	*10.61*		*14.80*	*15.57*	*0.329*	*0.273*	*0.262*	*0.158*	*0.369*	*0.409*	*0.243*	*0.045*	*51.64*	*155.78*	*181.48*
	rʎ	22.7			22.7	41.4	0.614	0.627	0.270	0.000	0.182	0.500	0.455	0.241	468.0	1,444.0	2,420.0
		8.17			*8.17*	*9.24*	*0.409*	*0.316*	*0.220*	*0.000*	*0.276*	*0.403*	*0.350*	*0.020*	*60.99*	*95.29*	*48.99*
	rʒ	20.0			20.0	41.9	0.656	0.650	0.235	0.000	0.125	0.406	0.156	0.262	460.0	1,485.0	2,380.0
		9.64			*9.64*	*19.07*	*0.376*	*0.255*	*0.211*	*0.000*	*0.231*	*0.462*	*0.129*	*0.023*	*63.25*	*57.45*	*69.28*
	rk	18.2	17.0		35.5	45.0	0.841	0.782	0.360	0.000	0.250	0.659	0.409	0.261	533.3	1,300.0	2,520.0
		7.51	*7.58*		*20.91*	*19.58*	*0.231*	*0.161*	*0.211*	*0.000*	*0.354*	*0.407*	*0.340*	*0.025*	*23.09*	*60.00*	
	ar# (1)	26.4	24.4	35.0	72.5		0.643	0.742	0.266	0.000	0.196	0.357	0.304	0.250	600.0	1,400.0	2,316.7
		23.41	*5.63*	*27.99*	*46.85*		*0.234*	*0.110*	*0.207*	*0.000*	*0.313*	*0.389*	*0.297*	*0.012*	*36.51*	*142.05*	*149.89*
	ar# (2)	42.5	36.4	35.0	90.7		0.667	0.690	0.175	0.000	0.000	0.367	0.533	0.254	580.0	1,324.4	2,176.0
		32.74	*29.26*	*30.41*	*49.22*		*0.323*	*0.237*	*0.135*	*0.000*	*0.000*	*0.421*	*0.281*	*0.020*	*50.00*	*91.53*	*126.02*

Data correspond to averages across repetitions and speakers of Majorcan (preconsonantal position only), Valencian and Eastern Catalan. Standard deviations are given in italics except for cases where a single token was computed. The two instances of /ar#/ in Valencian and Eastern Catalan correspond to the words *Gaspar* and *mar* in the former dialect and to *rar* and *car* in the latter.

There is more dorsopalatal contact for preconsonantal rhotics in Majorcan and Eastern Catalan than in Valencian, i.e. Qp values are above 0.2 for all clusters in the two former dialects and for only two clusters in the latter (table 6). Moreover, F2 is lower in Valencian (mean ranges are 1,283–1,607 Hz) than in Majorcan (1,239–1,755 Hz), and lowest in Eastern Catalan (1,167–1,485 Hz). F3 decreases in the progression Majorcan > Valencian, Eastern Catalan.

3.3.2 Utterance-Final Position

The Valencian speakers V.B., M.S. and V.G. produce the utterance-final rhotic with a single short contact, and thus as a tap, and always a vocal release (table 3). Speaker M.S. may also add some frication after the single contact: frication is the regular solution when the vowel preceding the rhotic is front (/i, e/) and vowel epenthesis when it is back (/a, ɔ/). Speaker J.M. always inserts an epenthetic vowel whether /r#/ exhibits one short contact (which may be nevertheless 90 ms long for *mar* and 60 ms long for *eixir*), or two short contacts in a single repetition of the words *Gaspar*, *mar* and *or*. According to the story data, his realizations of /r#/ may have a clear /l/ quality with an F2 frequency about 1,500 Hz. Finally, speaker A.V. produces utterance-final rhotics with one contact in the bisyllabic oxytones *Gaspar* and *eixir* (*sincer* does not count since 'r' is elided systematically here) and with two or three contacts in the monosyllabic oxytones *or* and *mar*, and only adds an epenthetic vowel to the one-contact rhotic of the word *Gaspar*. As shown in table 6, the duration of Valencian /r#/ is comparable to that of an intervocalic tap, i.e. 21–42 ms for the entire rhotic and 19–36 ms for the first or only contact period. The vocalic element, on the other hand, is about 89–105 ms long, and somewhat longer after low vs. front vowels.

The scenario is different in Eastern Catalan where /r#/ is generally realized as a trill mostly with three (speaker D.R.) or one or two (J.P., J.S.) contacts, and no vocalic element. Consistently with dialect-dependent differences in the number of contacts, the rhotic is much longer than in Valencian (72–91 ms). Moreover, the duration of the first contact (26–42 ms) does not exceed that of the second and third contacts and is comparable to the duration of the first contact for Valencian /r#/.

Both dialects also differ regarding the voicing status of the utterance-final rhotic, which is fully voiced in Valencian and partly voiceless in Eastern Catalan as a general rule. In Valencian, one-contact and two-contact rhotics are voiced all through while three-contact rhotics for speaker A.V. may devoice the second and third contact periods. As for Eastern Catalan, devoicing may start out at the first or second contact for J.S., at the second contact for J.P. and at the second or third contact for speaker D.R., and last until the very end of the rhotic.

As shown by the EPG patterns of figure 5 and by data in table 6, constriction degree varies as a function of speaker, word and context. In Eastern Catalan, speakers D.R. and J.P. occlude completely or partially the alveolar zone while J.S. does not. Regarding Valencian, the degree of constriction is higher in the monosyllabic words *mar* and *or* (CDC is about 0.9 in this case) than in the bisyllables *Gaspar*, *eixir* and *sincer* (0.5–0.6). Some speakers usually show complete closure in all repetitions of *mar* and *or* and leave a central passage in *Gaspar*, while others exhibit complete or almost complete closure in practically all tokens of all three words. There appears to be also an effect of vowel quality since CDC values are especially low when /r#/ follows a front vowel (for *eixir* and *sincer* vs. *Gaspar*), and indeed all speakers except for J.M. produced practically all tokens of the rhotic in the two former words without closure.

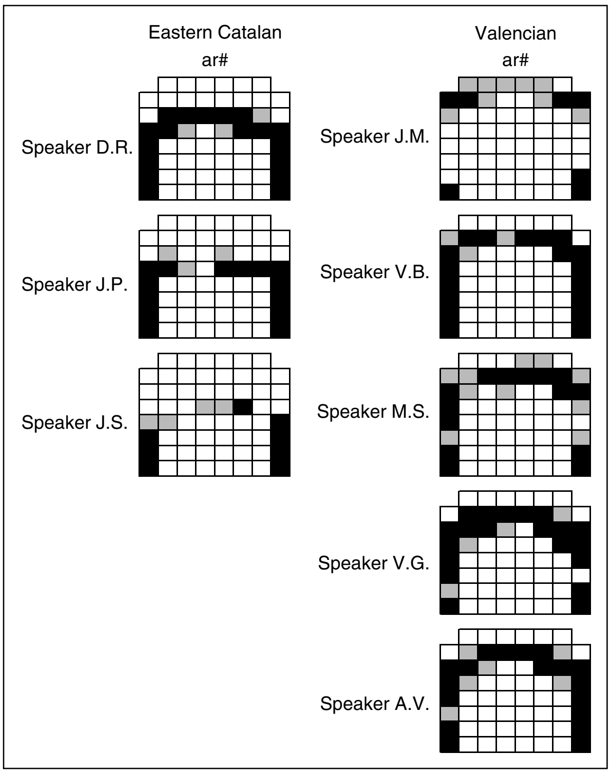

Fig. 5. Mean linguopalatal contact patterns for the utterance-final rhotic in the sequence /ar#/ in Eastern Catalan (word *car*) and in Valencian (word *mar*).

A comparison between CDC and CCa for /r#/ and for intervocalic /ɾ/ in similar contextual conditions, i.e. /ar#/-/aɾa/, /ir#, er#/-/eɾi/, and /ɔr#/-/wɾe/, reveals that the utterance-final rhotic is more constricted than the intervocalic one whether due to utterance-final strengthening, intervocalic weakening or other factors (tables 5, 6).

Dialect-dependent differences in place of articulation parallel those occurring in preconsonantal position, i.e. /r#/ is much more retracted in Eastern Catalan than in Valencian (mean CAa values in table 6 range between 0.17 and 0.27 in the former dialect and between 0.62 and 0.69 in the latter). Indeed, CDR values reveal that constriction location occurs at rows 3 and 4 in Eastern Catalan and at row 2 in Valencian. Qp values are also comparable to those for preconsonantal rhotics and thus, lower in Valencian.

3.3.3 Summary

Preconsonantal rhotics are produced with one voiced contact in Majorcan and Valencian, and have one or two contacts and may get devoiced in Eastern Catalan. Valencian realizations are shorter and more constricted than those in the other dialects, and trigger the insertion of longer vowels more often. Dialects also differ regarding constriction retraction (Eastern Catalan > Majorcan > Valencian), dorsopalatal contact degree (Majorcan, Eastern Catalan > Valencian), F2 (Majorcan > Valencian > Eastern Catalan), and F3 (Majorcan > Valencian, Eastern Catalan). These measures suggest that syllable-final rhotics are stronger in Eastern Catalan than in Majorcan and Valencian since they are longer and have more contacts, and perhaps stronger in Majorcan than in Valencian in line with differences in duration between the two dialects. Moreover, presumably stronger realizations involve more constriction retraction and more tongue dorsum lowering and backing (as cued by F2 but not by Qp). Analogously to taps in /Cɾ/ clusters, variations in constriction degree proceed independently of duration, i.e. in spite of being so short, Valencian rhotics are highly constricted. Frication was found to accompany rhotics in dental stop clusters.

Utterance-final /r#/ is realized essentially through a single voiced contact in Valencian, which may be more constricted and more anterior than that for the intervocalic tap, and takes a long schwa-like epenthetic vowel. Occasionally, it involves two voiced contacts, and the epenthetic vowel may be replaced by friction in front vowel sequences. Speaker A.V. is special in that he alternates voiced taps with an epenthetic vowel and voiced or devoiced trills without it. In Eastern Catalan, /r#/ is realized as a voiced or devoiced trill with contact periods of similar duration or as a voiced tap, does not insert an epenthetic vowel after it, and is more retracted and exhibits some more palatal contact than /r#/ in Valencian.

4 Discussion

Articulatory and acoustic differences between taps and trills were found to hold invariantly across dialects, i.e. less dorsopalatal contact and a lower F2 for /r/ vs. /ɾ/, which is in support of tongue dorsum activity being a major articulatory attribute of highly constrained consonants such as alveolar trills and dark /ɫ/. Both consonant classes were not always differentiated by place of articulation, however: while the trill is more retracted than the tap in Eastern Catalan, no clear differences in alveolar constriction location occur in Valencian and Majorcan. Data for syllable-initial rhotics reveal the existence of dialect-dependent articulatory differences for each rhotic class. Trills show some preference for increasing the number of contacts in Valencian and for lengthening the first contact period in Majorcan, and Eastern Catalan trills are more retracted than trills in the other two dialects. Taps are longer and less anterior, and show more dorsopalatal contact, a higher F2 and a lower F1, in Majorcan than in Valencian. A lower F3 for taps and trills in Valencian than in Majorcan appears to be associated with a larger sublingual cavity and perhaps more apical realizations.

Dialects could also exhibit different principles of articulatory organization tied to syllable structure. Indeed, data reported in the present study suggest that there is a compensatory relationship between initial strengthening, and intervocalic weakening and the absence of syllable-final strengthening, for Valencian rhotics. Regarding the initial and intervocalic positions, it was found that, in comparison to Majorcan trills, Valencian trills exhibit a narrower constriction and a higher F2 in /#r/ and /Cr/ sequences, and a wider constriction, less dorsopalatal contact and a lower F2 in /VrV/ sequences. Also, in comparison to Majorcan taps, Valencian taps are more constricted in strong positions (/Cɾ/), and shorter and less constricted in weak positions (/VɾV/). As to the syllable-final position, there is a clear trend for rhotics to be reinforced in Eastern Catalan such that they are often implemented as trills in this dialect and as taps in Valencian and Majorcan. This was mostly so for /r#/, which is generally produced with two or three contacts in the former dialect and with a single contact in the latter two. Moreover, in comparison to Valencian and Majorcan, final /r/ in Eastern Catalan was found to be produced with more place retraction, more tongue dorsum lowering and retraction (as cued by F2), and no vocalic release prepausally. Rhotic weakening in the intervocalic and syllable-final positions may be a reflection of a more general trend towards consonant weakening in Valencian, and could be associated with a principle of intersegmental timing organization according to which vowels become especially salient vis-à-vis consonants in the nucleus-coda portion of the syllable [see Smith, 1995, for possible evidence in support of this organization principle for other languages].

Several position-dependent articulatory and acoustic characteristics for Valencian taps could be associated with the extremely short /ɾ/ duration in this dialect. Thus, little dorsopalatal contact, and a relatively low F2 and a high F1, for Valencian /ɾ/ could occur because a fast ballistic apical movement may not leave enough time for the tongue dorsum to reach the palate. Given that the tap is so short, much constriction narrowing in strong word and utterance positions could be accounted for assuming that speakers need to make sure that the consonant will be produced with a sufficient degree of central contact so as to prevent undershoot from occurring. This case reveals that shortening and articulatory reduction are not necessarily related for extremely short consonants.

In addition to dialectal differences, data reported in our study are also informative about general principles on rhotic production.

Evidence has been provided for initial and final rhotic reinforcement not being necessarily related to the number of contacts and being implemented through different production mechanisms. In comparison to the /Cr, VrV/ conditions, /#r/ exhibits quite often one long contact followed by a well-defined approximant phase or several contacts with a long first occlusion. It may be claimed that, while a long contact may be sufficient for a rhotic to sound like a trill utterance-initially, a postconsonantal trill is required to have two contacts presumably since the first contact is necessarily short in this case. Initial strengthening also accounts for the systematic presence of a complete closure (in /#r, Cr/ vs. /VrV/ sequences), and for more place retraction and a higher tongue body position presumably in order to facilitate the production of the long first contact period for the trill (in /#r/ vs. /VrV/ sequences). The strengthening of final rhotics, on the other hand, appears to be implemented through overall lingual retraction and lowering without necessarily an increase in the number of contacts.

Syllable-final rhotics are not in free variation. Instead, dialects favor one particular realization over another, and the alternation between taps and trills may be determined by context and other factors. Moreover, trills are often more reduced in syllable coda position than in syllable-initial position: in Eastern Catalan, strengthened syllable-final rhotics are more tap-like than syllable-initial trills in /Cr, VrV/ strings since the number of contacts may be one in the /rC/ and, less so, /r#/ conditions.

Position and context may account for other production events. Trills may devoice in line with favorable aerodynamic factors preventing vocal fold vibration from taking place in utterance-initial position (also because the lingual gesture for /#r/ undergoes much anticipation) as well as utterance-finally. Frication is associated with a burst occurring at the first contact period of trills in the /#r, Cr/ conditions. Both devoicing and frication may also occur next to a voiceless stop consonant in /Cɾ/ clusters followed by /i/, in /rC/ clusters such as /rt/, and in utterance-final taps after a front vowel. These realizations may be at the origin of fully assibilated rhotics [see evidence from Spanish dialects in Navarro Tomás, 1972]. Articulatory and aerodynamic factors may be adduced in order to explain why rhotics may not reach a complete occlusion in specific contextual environments, e.g. before /i/ and before a lingual fricative or other alveolars. Vowel epenthesis in /Cɾ, rC/ clusters is more prone to occur when the rhotic appears next to voiced vs. voiceless consonant and in /rC/ sequences with heterorganic consonants. Moreover, there appears to be an inverse relationship between the frequency of occurrence and the duration of the epenthetic vowel, on the one hand, and rhotic duration, on the other hand, which makes sense if we assume that vowel duration should be conditioned by the speed of the tongue tip movement for the tap.

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